Science with Seeded SASE Beams

SPring-8 Angstrom Compact free-electron LAser

Plan for seeded XFEL upgrade at SACLA

Makina YABASHI, Takashi TANAKA, and Hitoshi TANAKA

RIKEN SPring-8 Center (RSC), XFEL R&D Division

yabashi@spring8.or.jp

July 19, 2012 @DESY, Hamburg, Germany

Contents

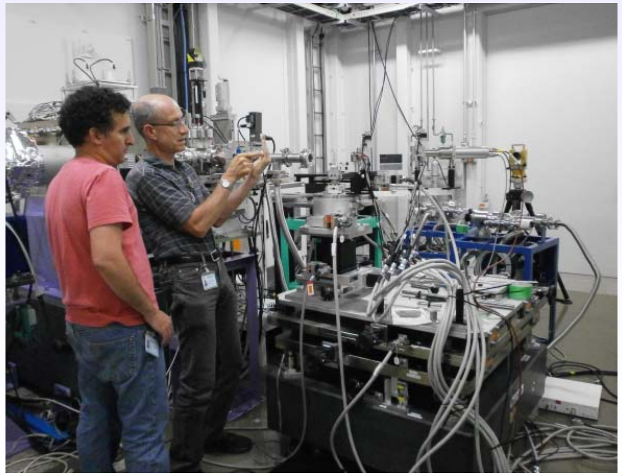
Overview of SASE operation at SACLA

Seeded HX-FEL upgrade

Seeded SX-FEL upgrade

First Lasing of SACLA: June 7, 2011

- Start User operation in March 2012
- 25 user proposals have been performed in 2012A (March ~ July)
- Operation is mostly well going



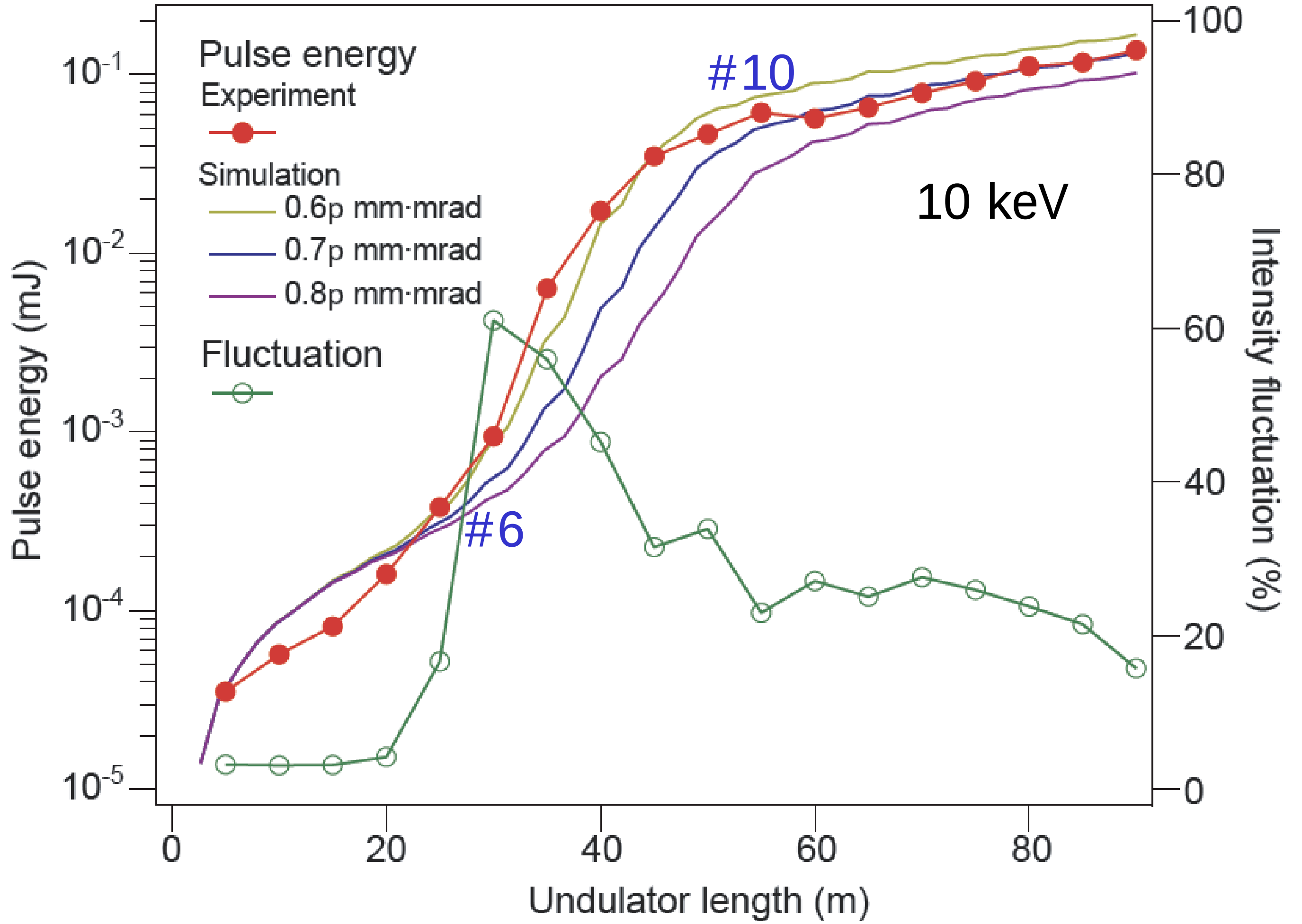
Performance of SASE: Gain Curve

nature photonics | LETTERS

PUBLISHED ONLINE: 24 JUNE 2012 | DOI: 10.1038/NPHOTON.2012.141

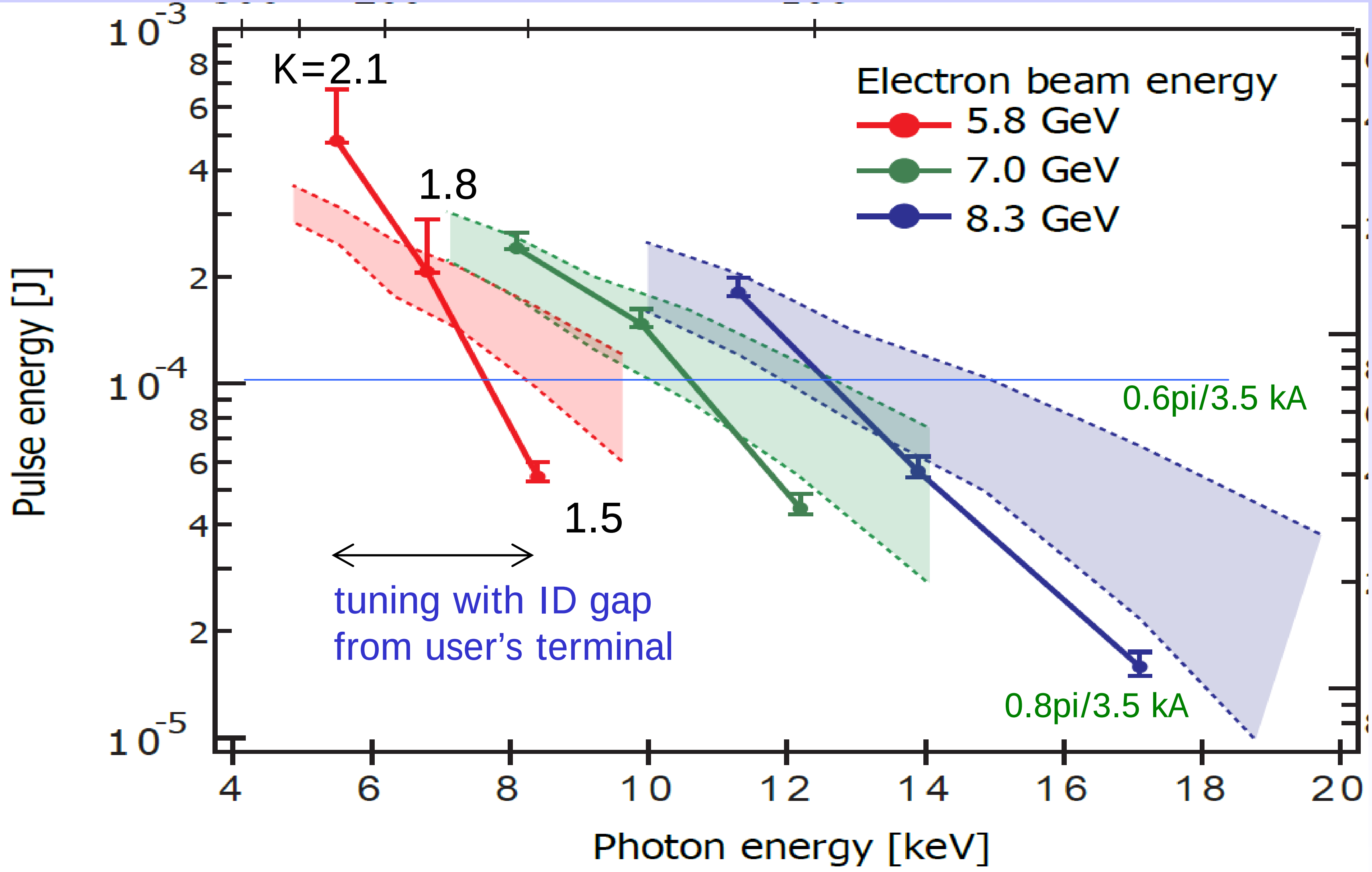
A compact X-ray free-electron laser emitting in the sub-ångström region

T. Ishikawa et al, Nat. Photon (2012)

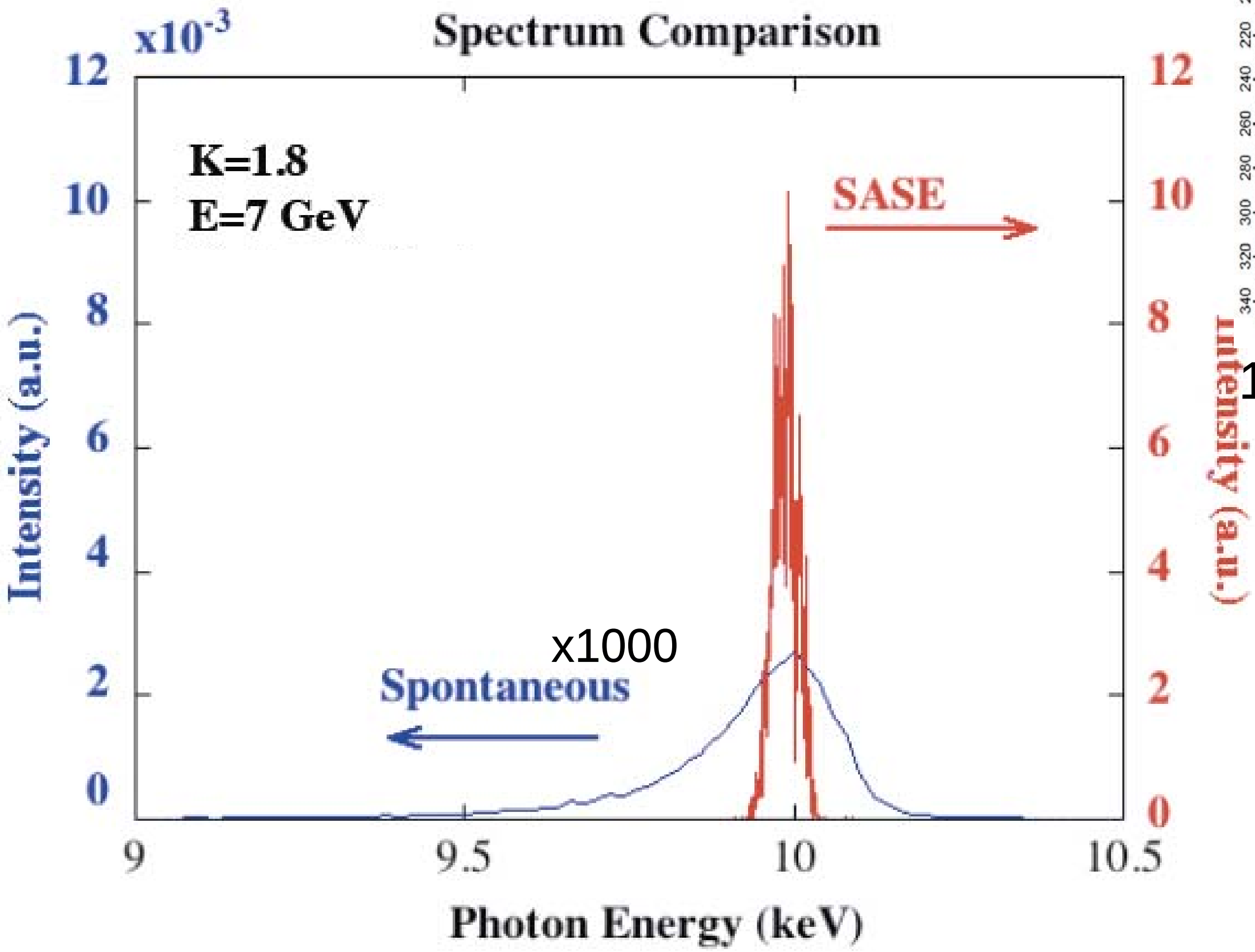


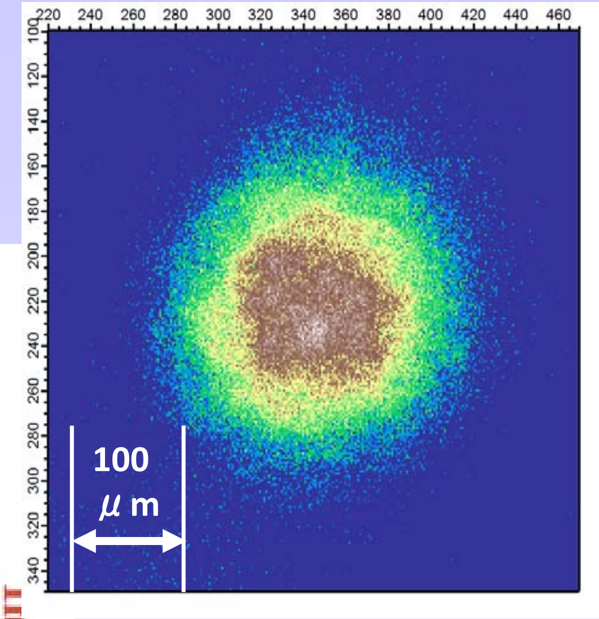
E-beam: ε_n=0.7 πmm.mrad, I_p=3.5 kA, τ_{FWHM}=20 fs

Wavelength & Pulse energy

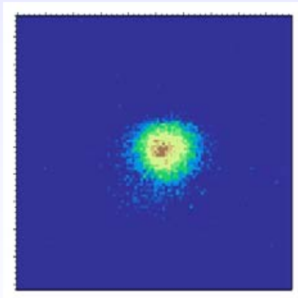


Spatial profile (transverse) & spectrum (longitudinal)



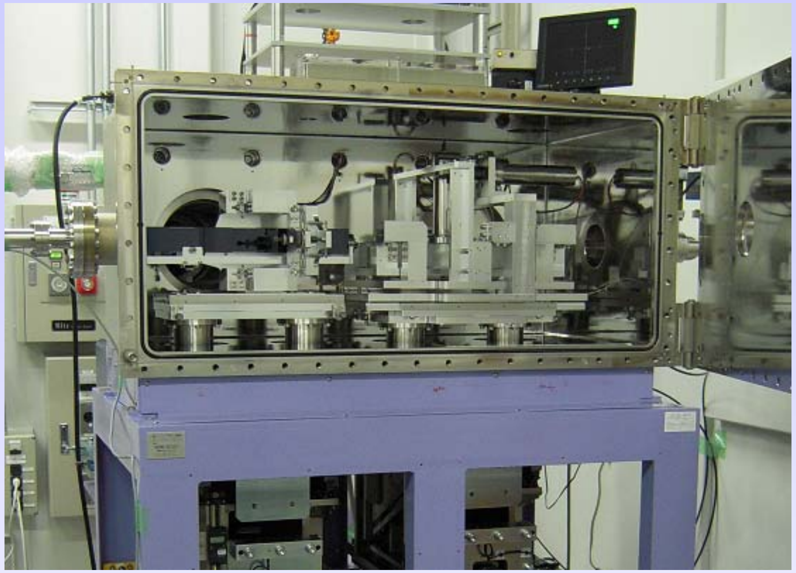


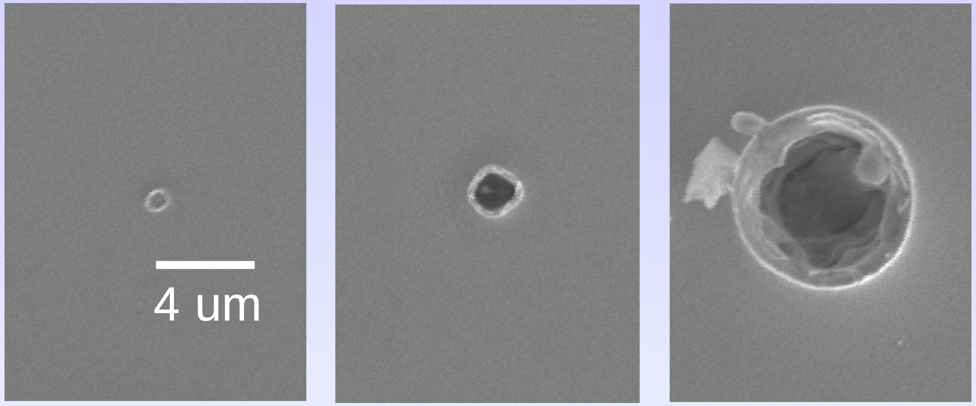
110 m from exit of ID18



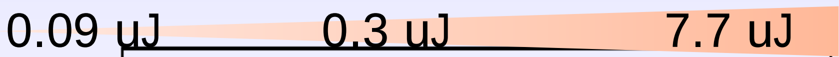
1-um Focusing

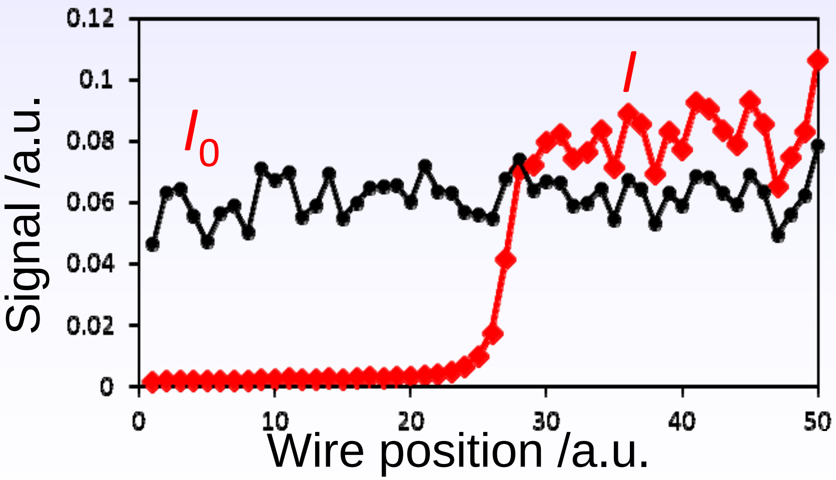
Osaka U: Yamauchi et al
U Tokyo: Mimura et al
SACLA/SP8: Ohashi, Yumoto, Koyama, Tono et al

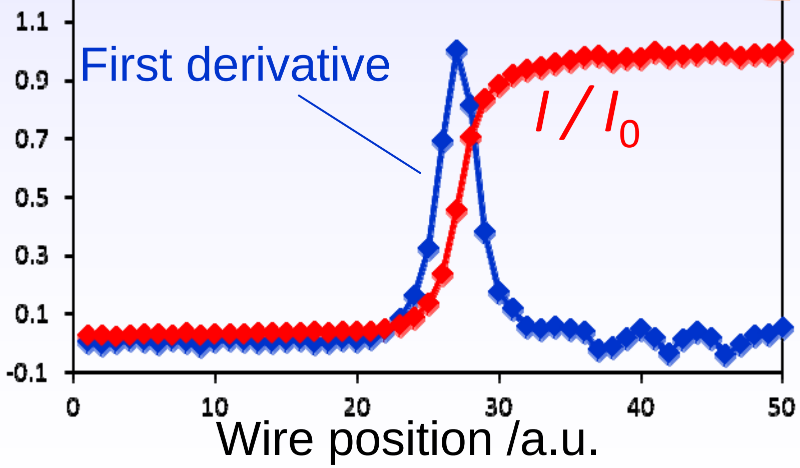


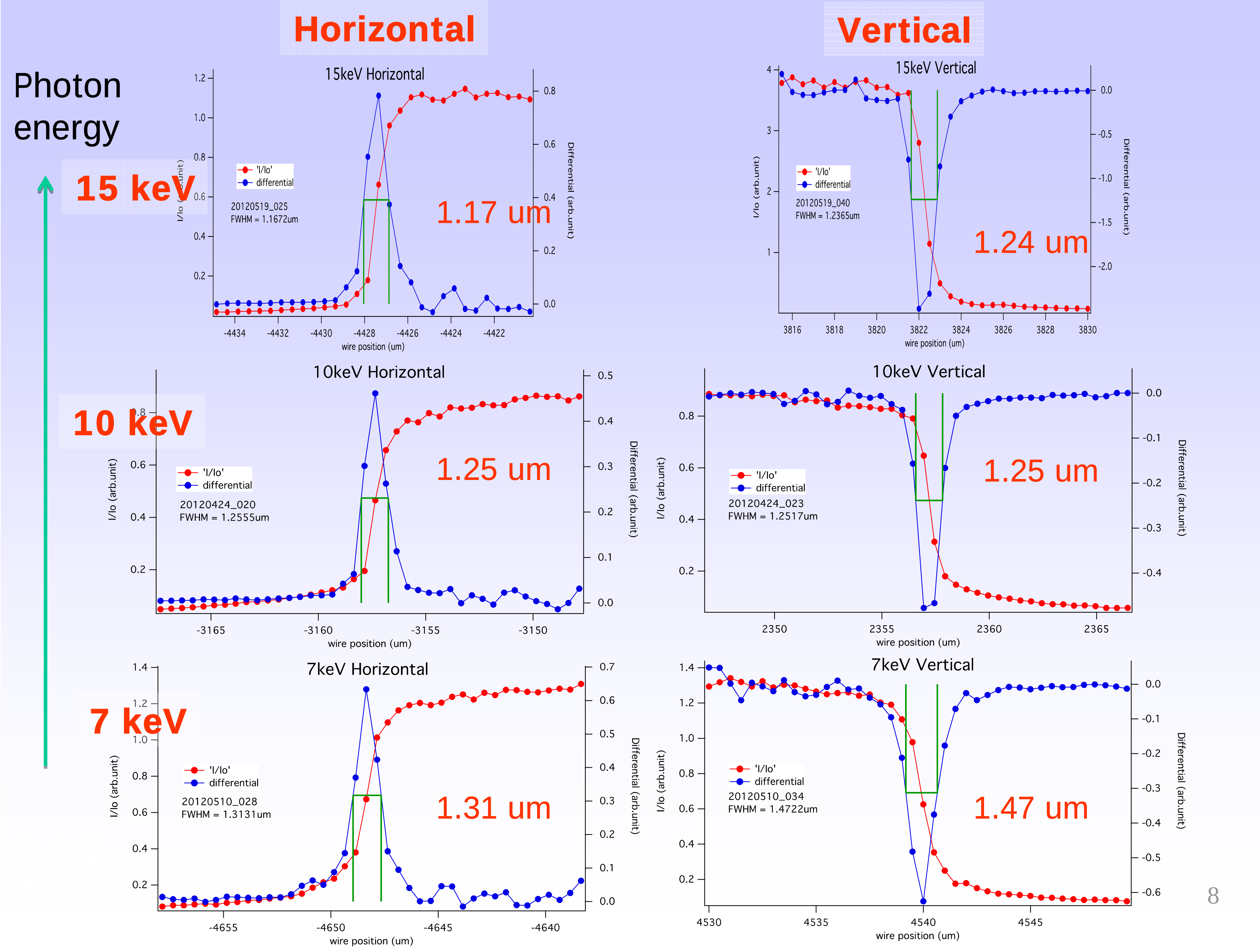


Pt(1.4 um)/Si

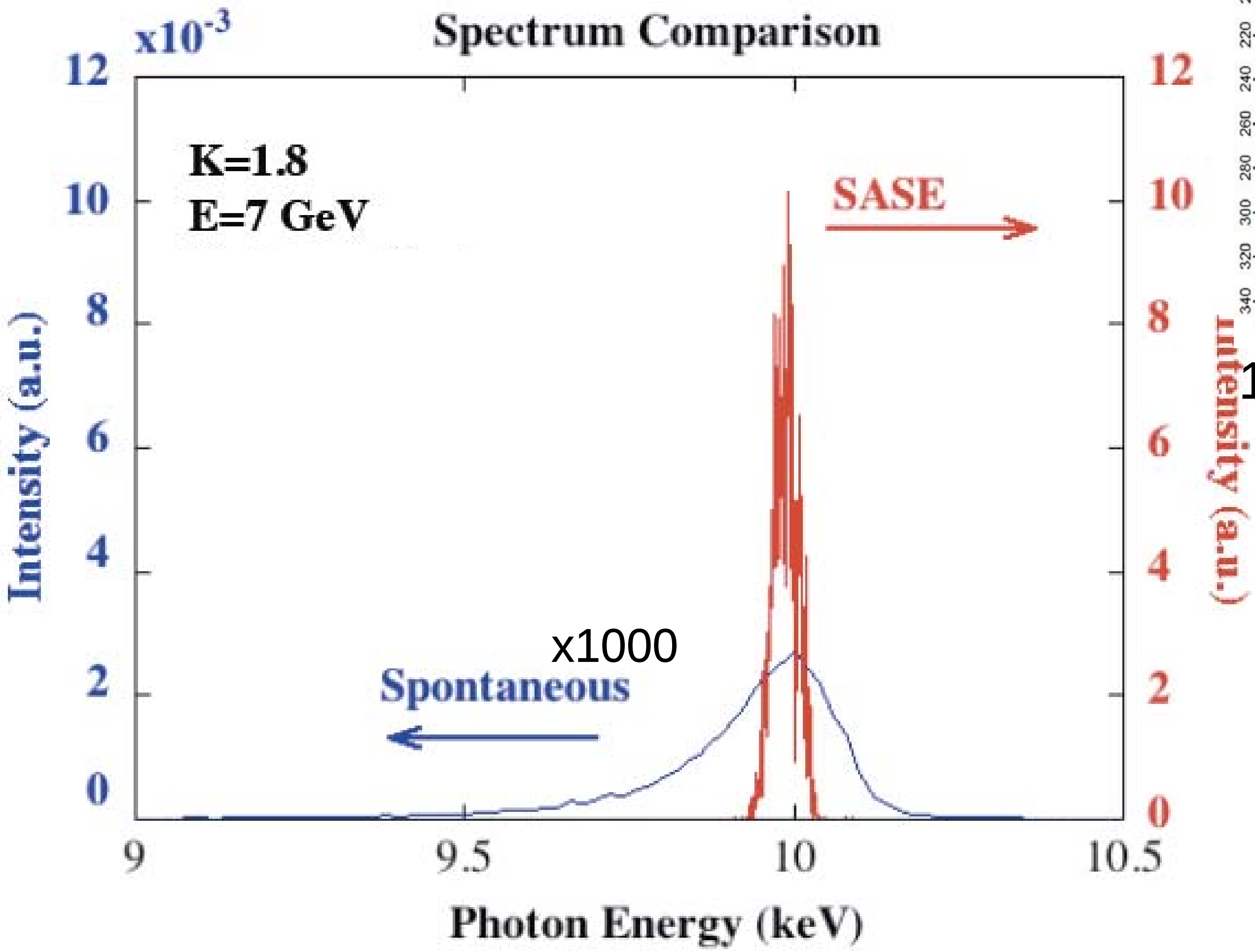


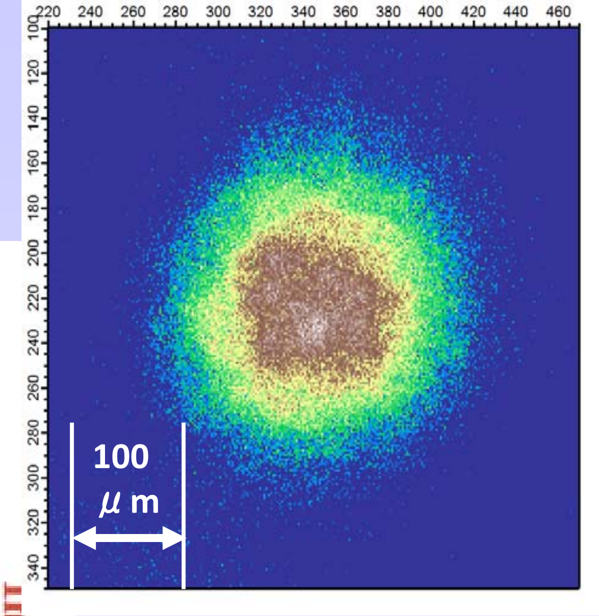





Horizontal
Vertical
Photon energy
15 keV
10 keV
7 keV
15keV Horizontal
'I/Io'
differential
20120519_025
FWHM = 1.1672um
1.17 um
wire position (um)
Differential (arb.unit)
15keV Vertical
'I/Io'
differential
20120519_040
FWHM = 1.2365um
1.24 um
I/Io (arb.unit)
wire position (um)
Differential (arb.unit)
10keV Horizontal
'I/Io'
differential
20120424_020
FWHM = 1.2555um
1.25 um
I/Io (arb.unit)
wire position (um)
Differential (arb.unit)
10keV Vertical
'I/Io'
differential
20120424_023
FWHM = 1.2517um
1.25 um
I/Io (arb.unit)
wire position (um)
Differential (arb.unit)
7keV Horizontal
'I/Io'
differential
20120510_028
FWHM = 1.3131um
1.31 um
I/Io (arb.unit)
wire position (um)
Differential (arb.unit)
7keV Vertical
'I/Io'
differential
20120510_034
FWHM = 1.4722um
1.47 um
I/Io (arb.unit)
wire position (um)
Differential (arb.unit)

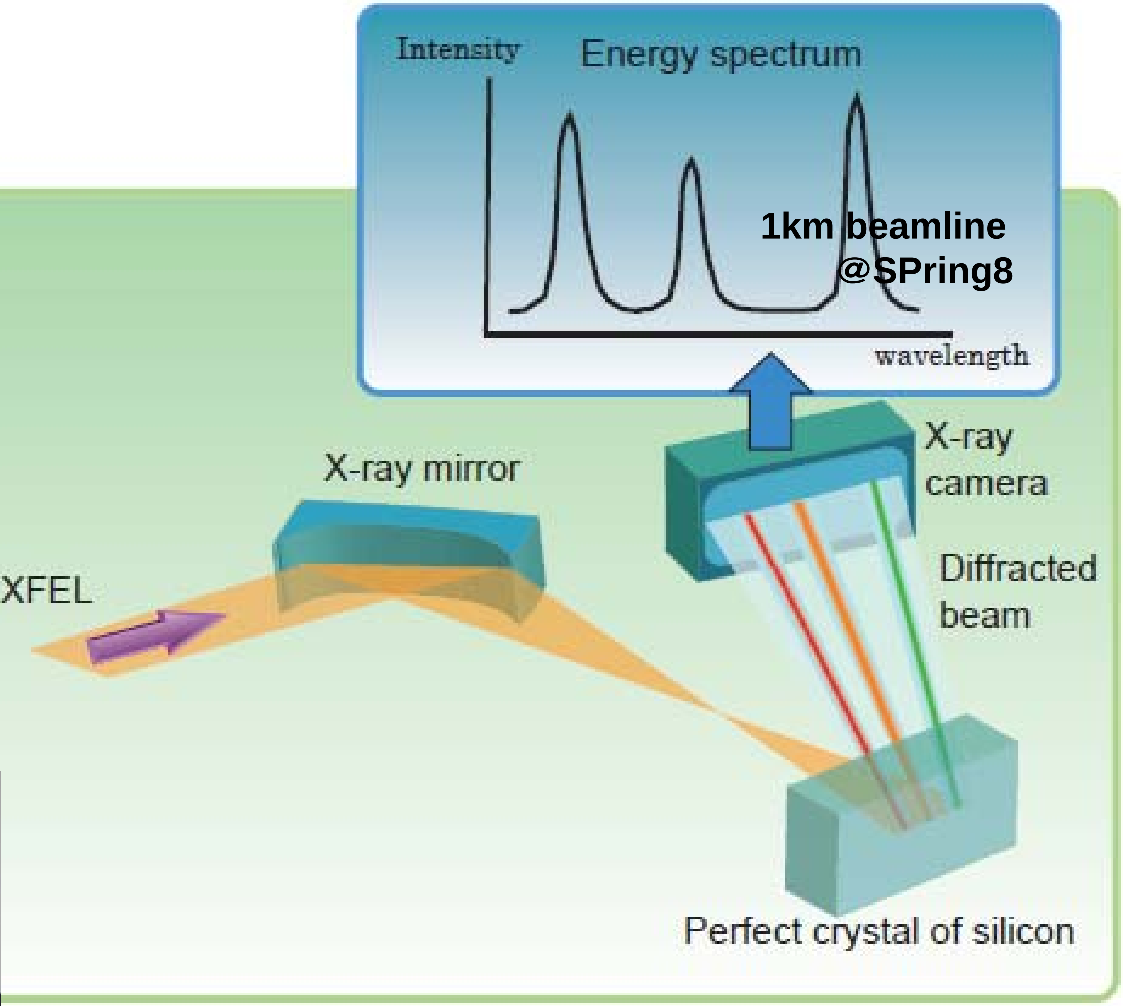
Spatial profile (transverse) & spectrum (longitudinal)

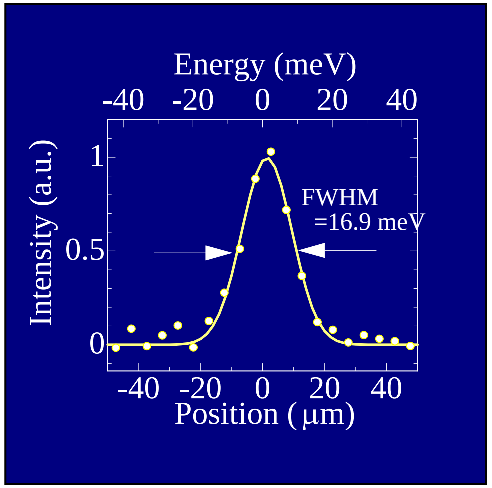




110 m from exit of ID18

Single-shot high-resolution spectrometer



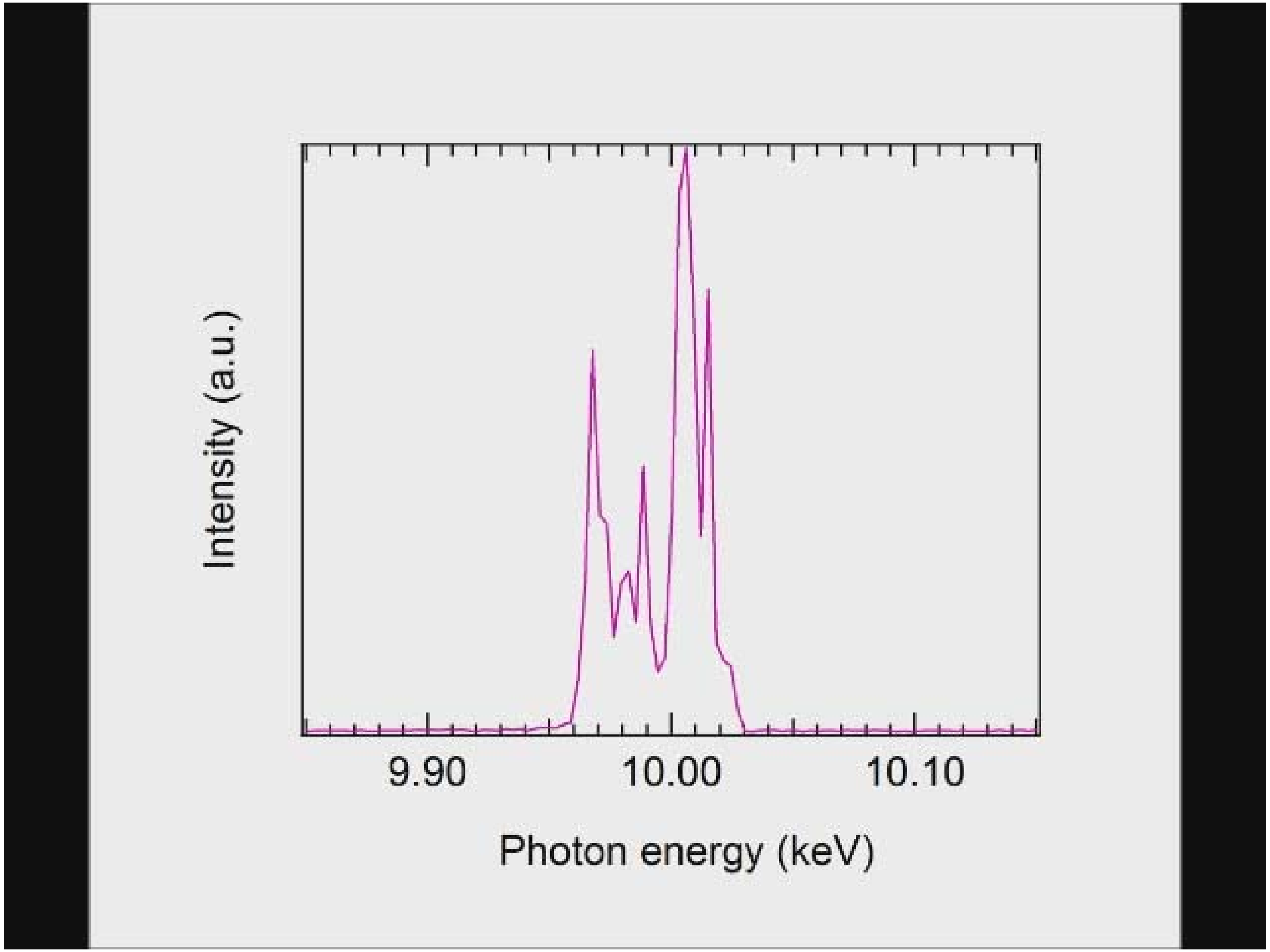


ΔE = 13.1± 1.9 meV
$\Delta E/E$ = 1.3e-6

Inubushi et al.

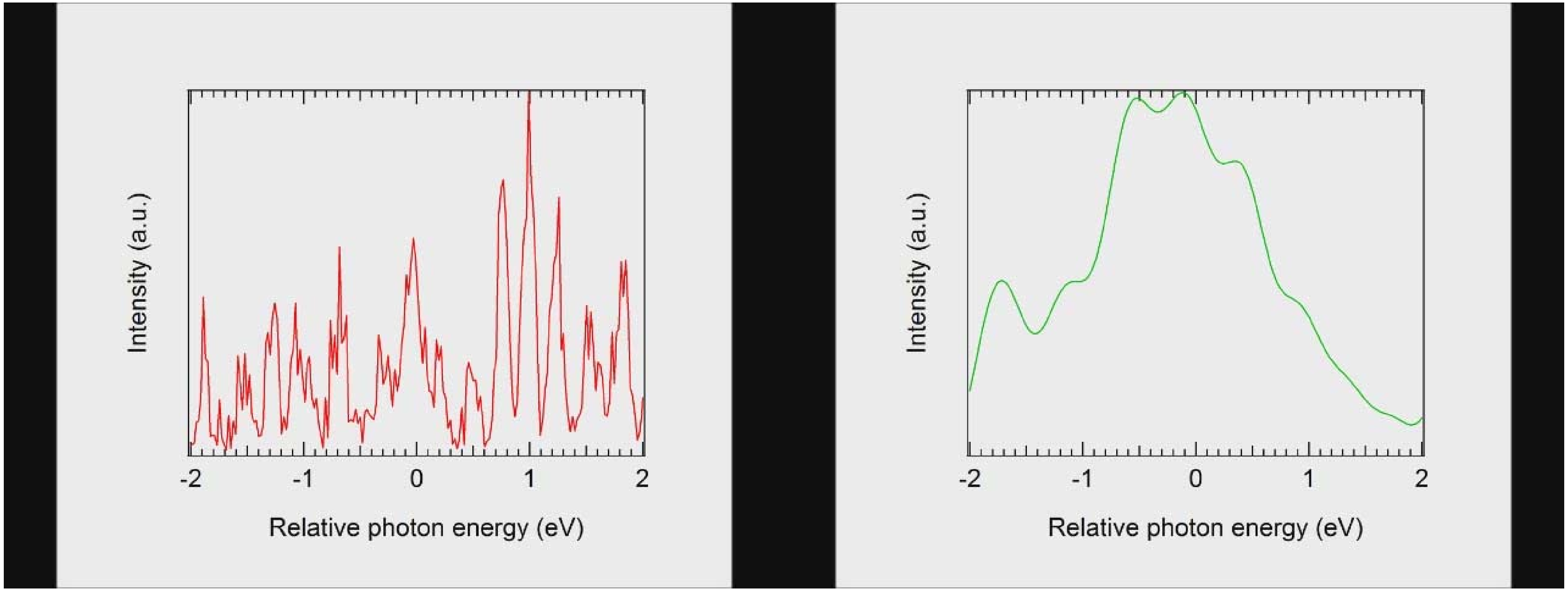
Yabashi et al, PRL (2006)

SACLA Single-shot spectra (ΔE~ 1 eV w Si 111)



Spike profiles change in every shot, while central energy is stable

Single-shot high-resolution **(20 meV)** spectra with Si 555



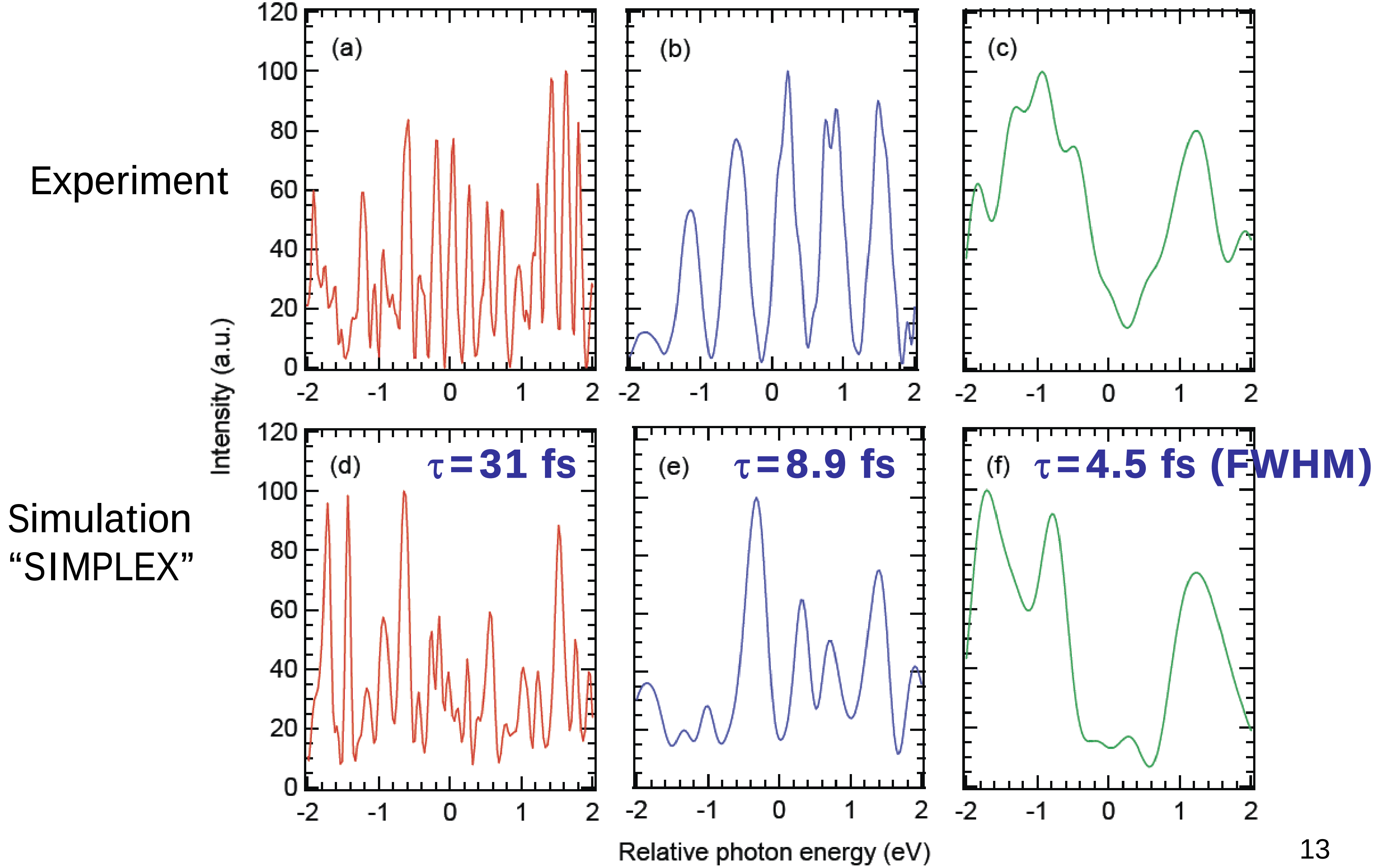
Narrow ⇐ Spike width in freq. domain ⇒ Broad

Long ⇐ Bunch duration ⇒ Short

Fourier relationship between temporal and frequency

Analysis with FEL simulation

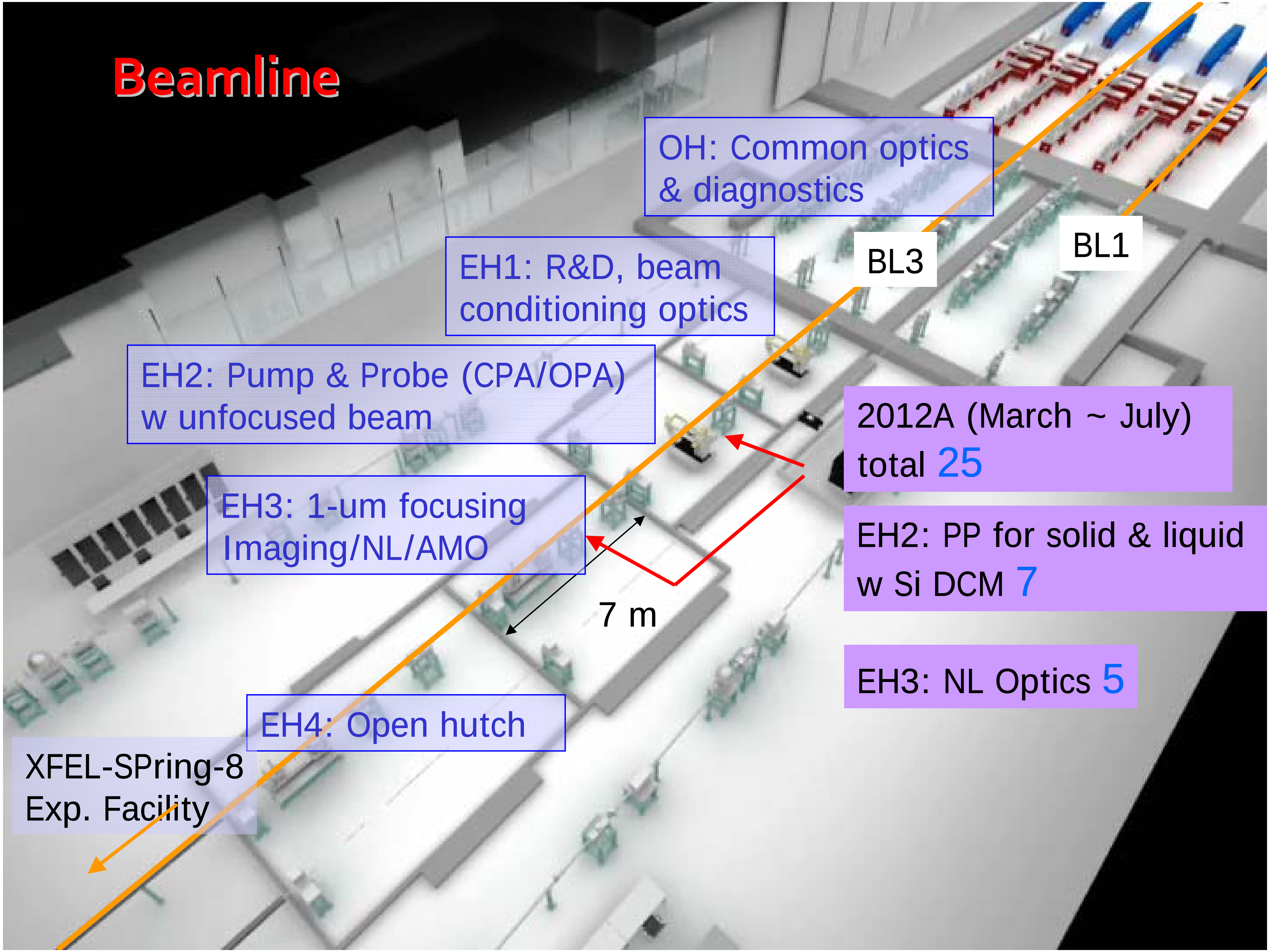
Inubushi et al, submitted



Summary of performance

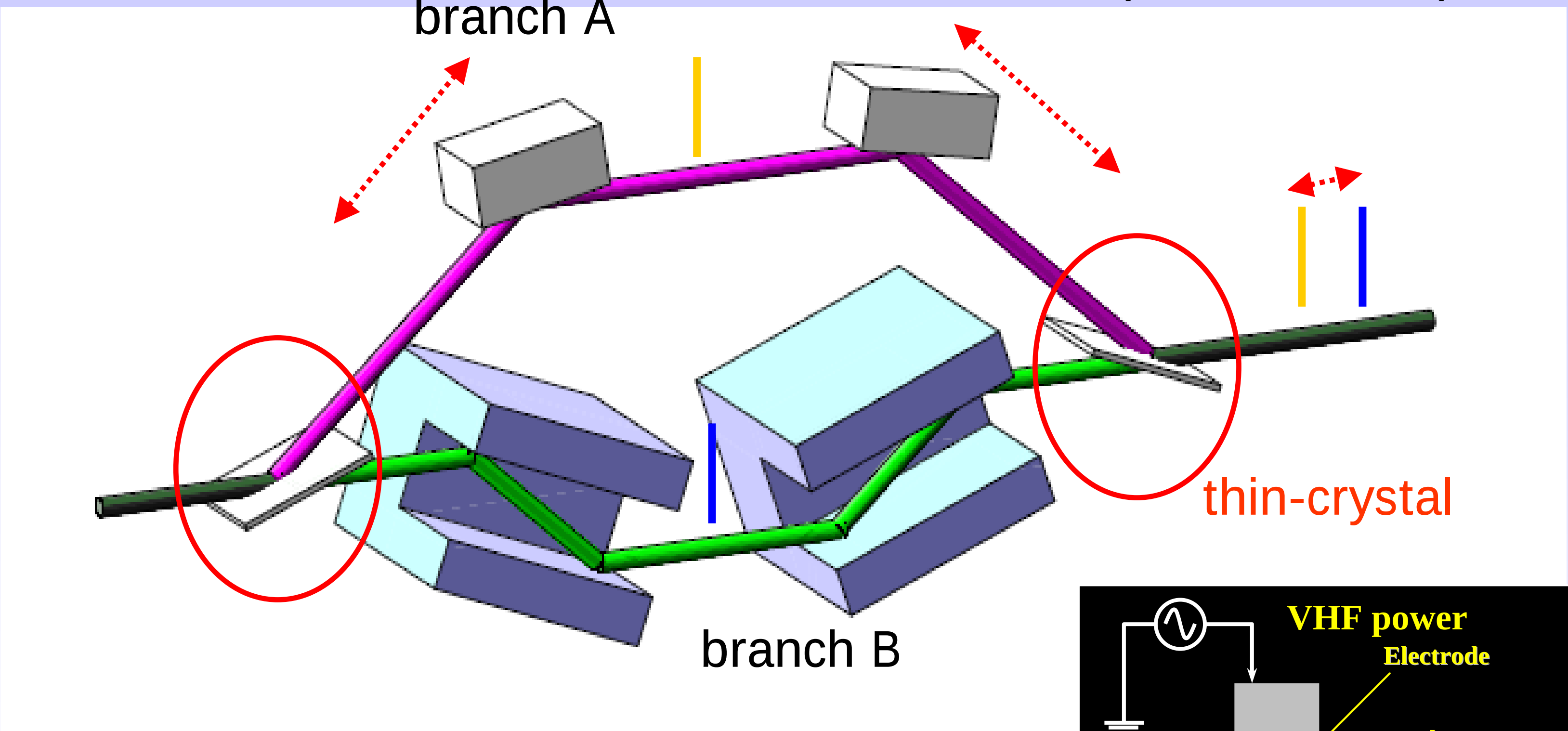
	Design	Achieved
Photon energy	<20 keV	4~20 keV
Spec. Bandwidth	3e-3	~5e-3
Fluctuation of photon energy	<< b.w.	~1e-3 (<<b.w.)
Pulse energy	sub-mJ/pls	>0.5 mJ/pls @ 5 keV ~0.2 mJ/pls @ 10 keV ~0.1 mJ/pls @ 15 keV
Peak power	~ 10 GW	~ 10 GW
Pulse duration	<30 fs	5~30 fs
Rep rate	60 Hz	10 Hz

Beamline


OH: Common optics & diagnostics
EH1: R&D, beam conditioning optics
EH2: Pump & Probe (CPA/OPA) w unfocused beam
EH3: 1-um focusing Imaging/NL/AMO
EH4: Open hutch
XFEL-SPring-8 Exp. Facility
BL3
BL1
7 m
2012A (March ~ July) total 25
EH2: PP for solid & liquid w Si DCM 7
EH3: NL Optics 5

X-ray autocorrelator: NL, XPCS etc.

Osaka U (Yamauchi-lab): Osaka, Sano

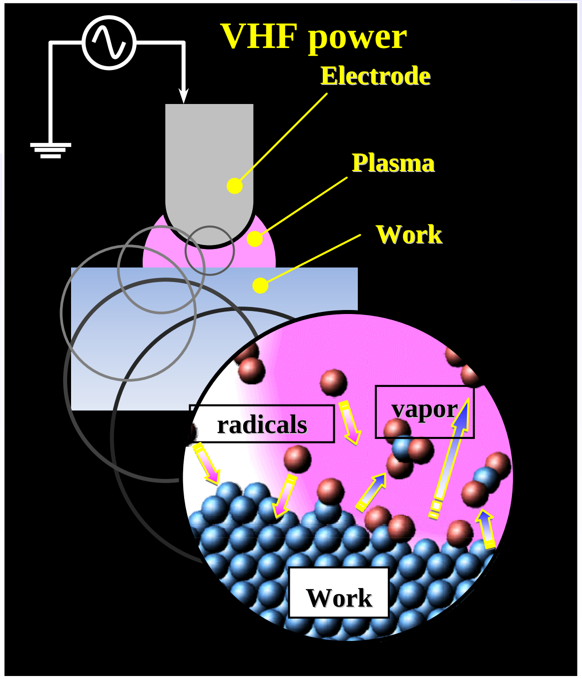


Roseker, Grübel, et al, OL **34**, 1768 (2009)

XPCS and nonlinear studies

Strain-free thin crystal for Bragg beam splitter

Atmospheric plasma etching (PCVM)



from SASE to seeded XFEL

Goal

Improvement of longitudinal beam properties

- Remove of spiky spectra in frequency and time
- Design of pulse characteristics (i.e., ultrashort pulse, narrow b.w.)

Increase of brilliance & monochromatic intensity

Requirement

Wavelength tunability

Wavelength range

Switch back to SASE mode

Technologies

HX: Self-seeding with single diamond crystal

Gianluca Geloni et al

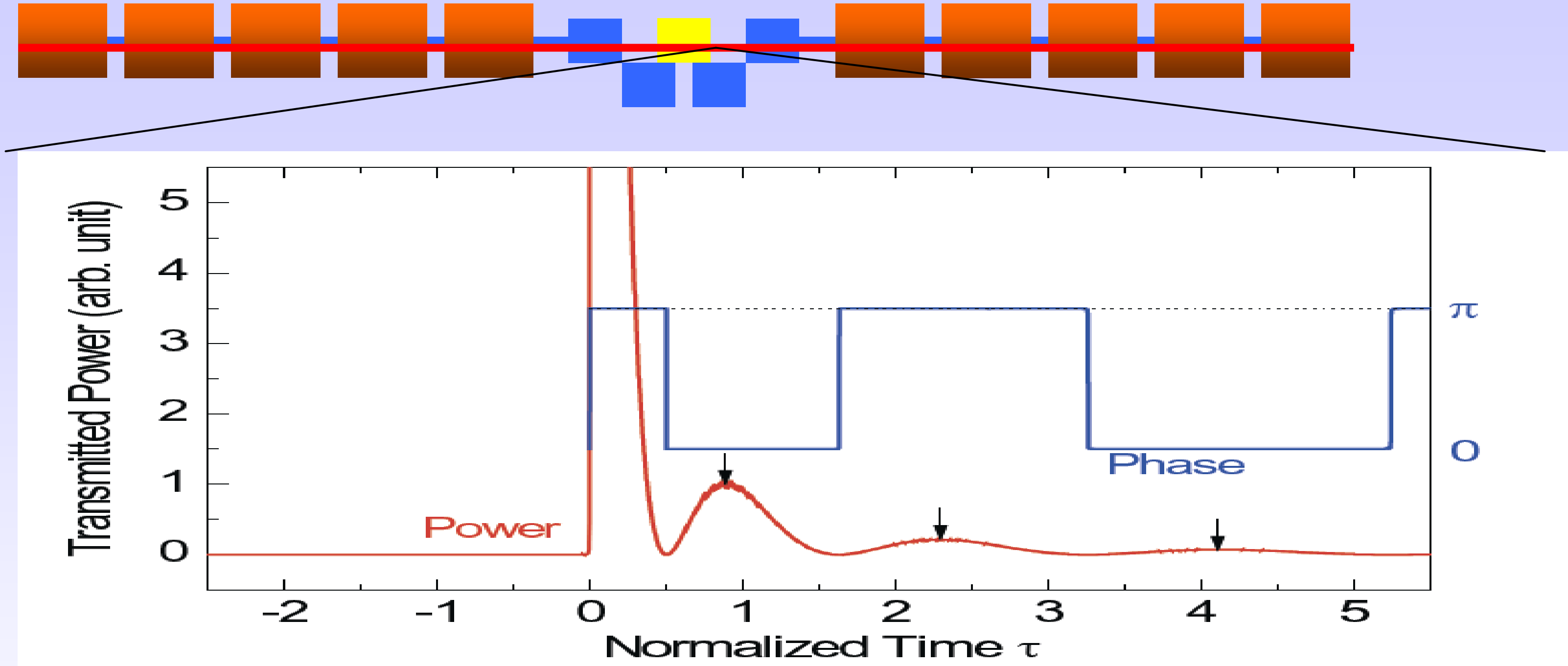
SX: Combination of optical laser, self-seeded

Simulation of SS

by Takashi Tanaka

E-beam: E_B= 8 GeV, ε_n=0.7 pmm.mrad, I_p=3.6 kA, τ_{FWHM}=20 fs

Undulators (1st stage) Undulators (2nd stage)



C(400) with 100-um thickness

Photon energy	Bragg angle	τ_1	τ_2
10 keV	44.1 deg	14.6 fs	37.7 fs
15 keV	27.6 deg	9.7 fs	25.1 fs

$$t_i \propto \frac{\sin\theta_B}{d}$$

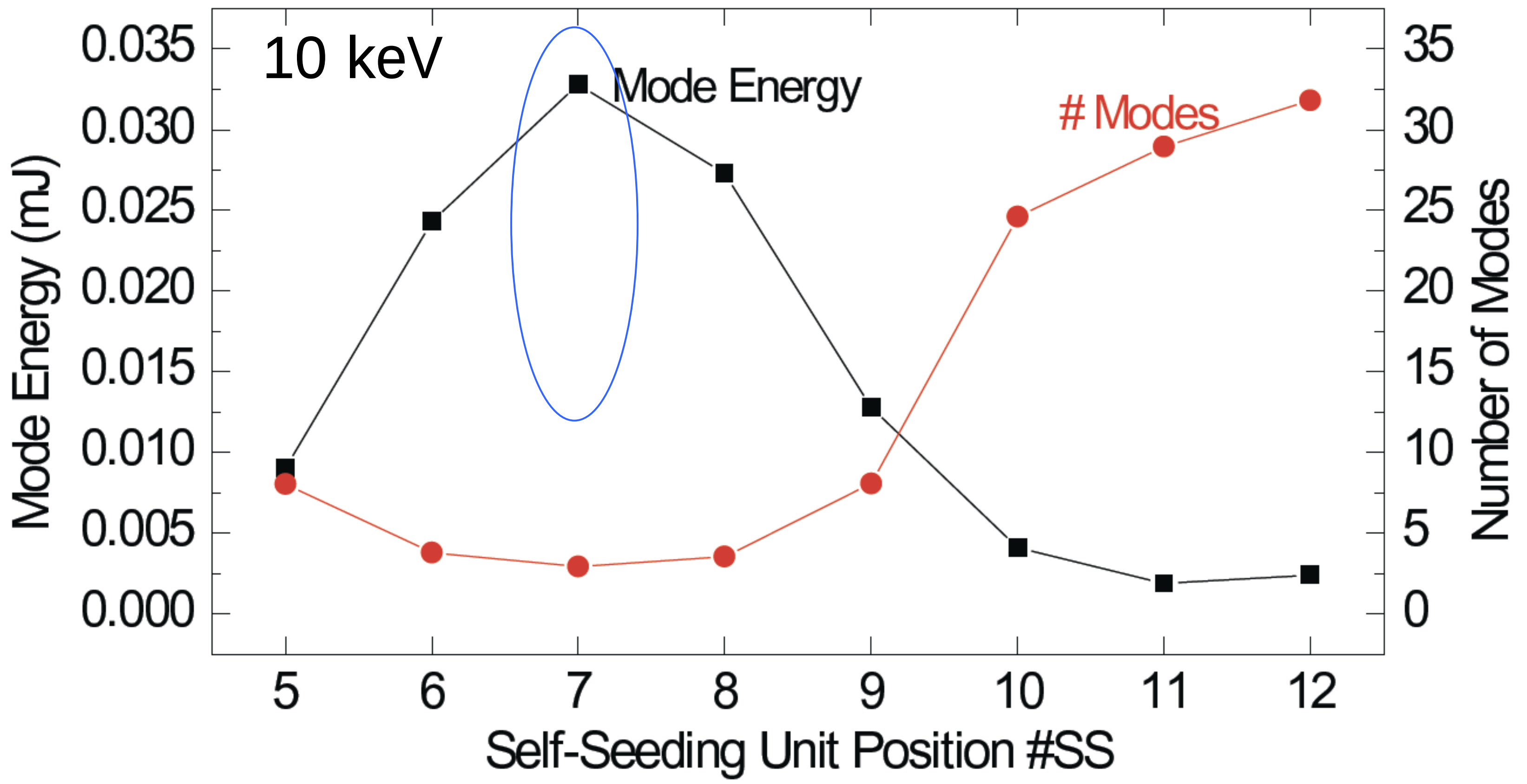
(Cf. Lindberg & Shvyd'ko PRST 2012)

E-bunch duration: 20 fs

by Takashi Tanaka

Optimization of monochromator position

Mode Energy: $E_{\mathrm{mode}} = E_{\mathrm{pulse}} / M_{\mathrm{T}}$

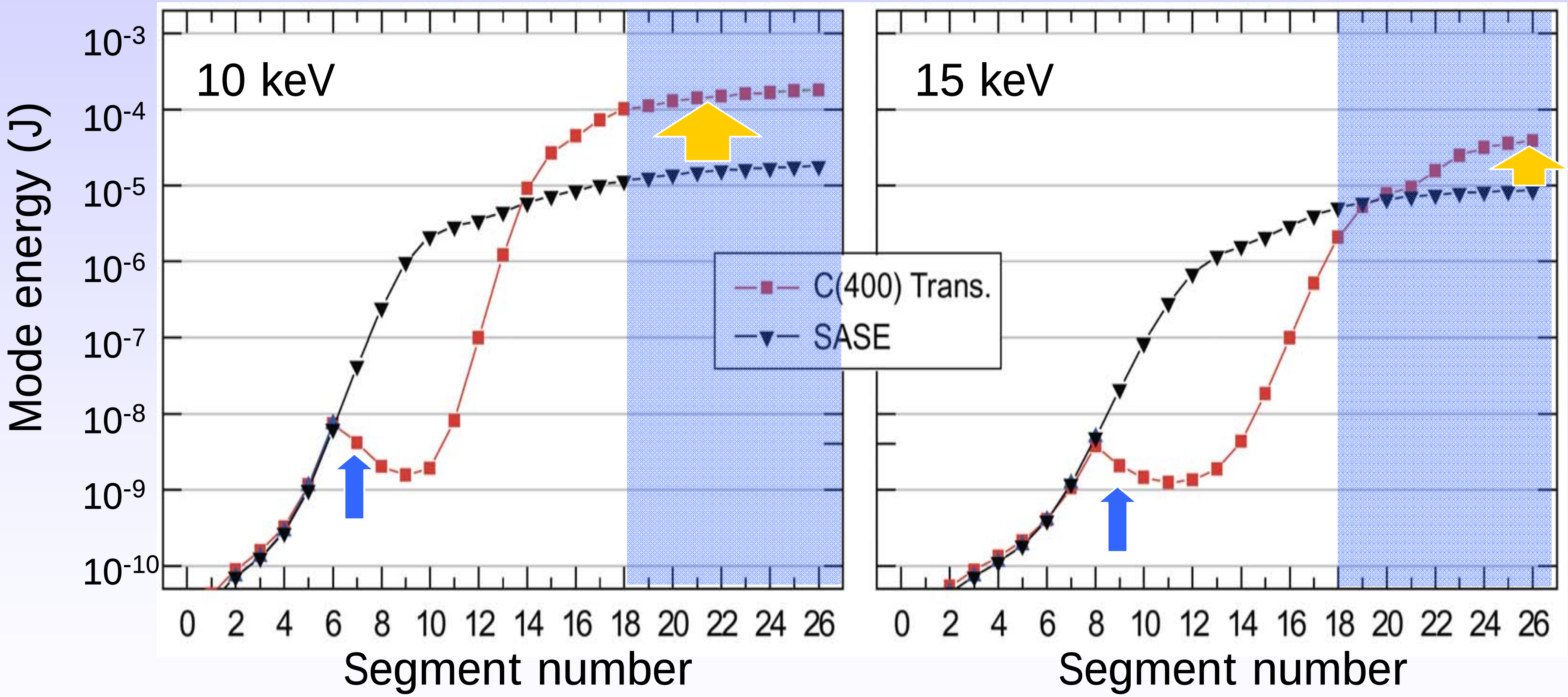


Mode energy of SS & SASE

by Takashi Tanaka

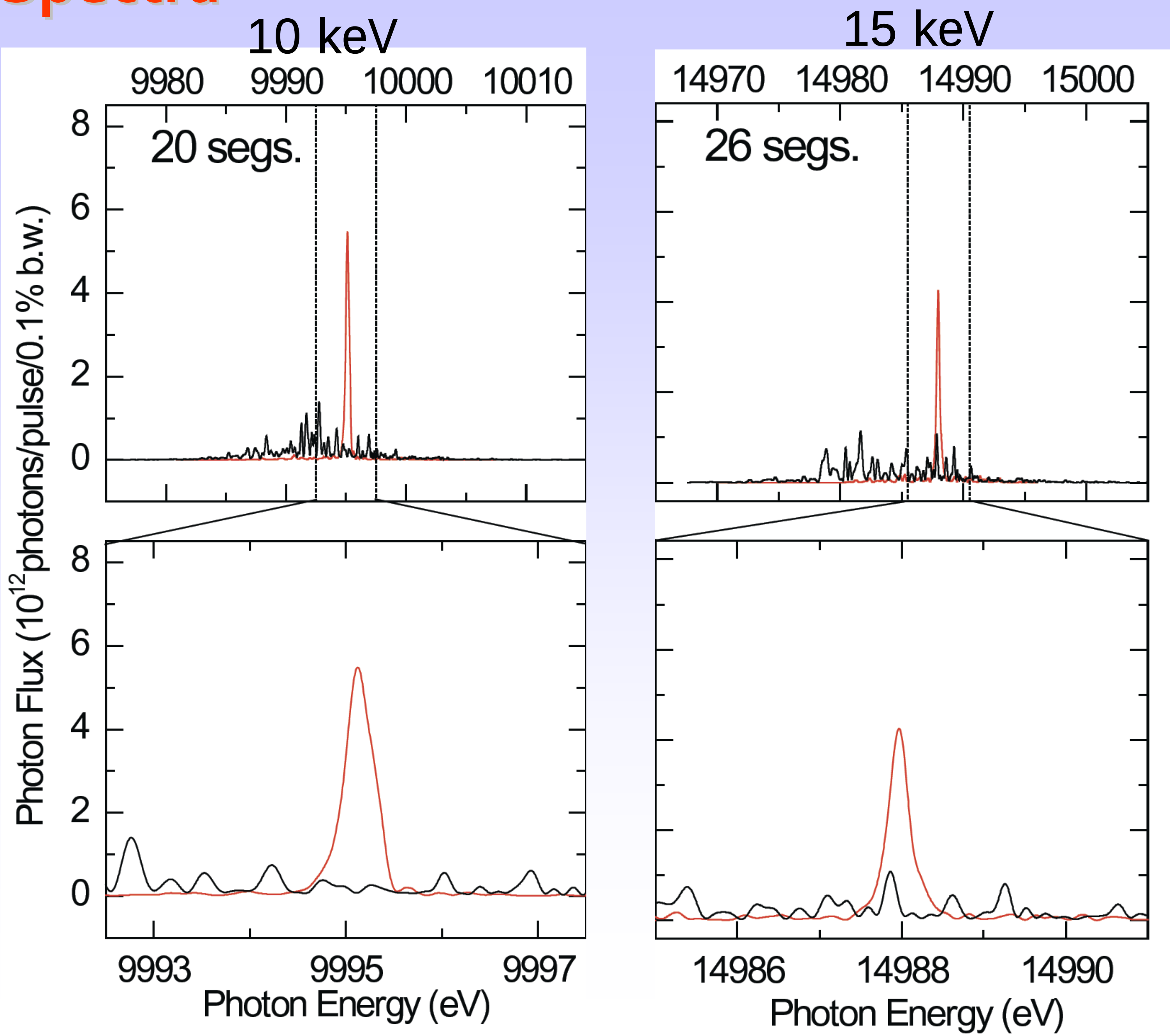
Mode Energy: $E_{mode} = E_{pulse} / M_T$

Present # of ID: 18 Maximum #: 26



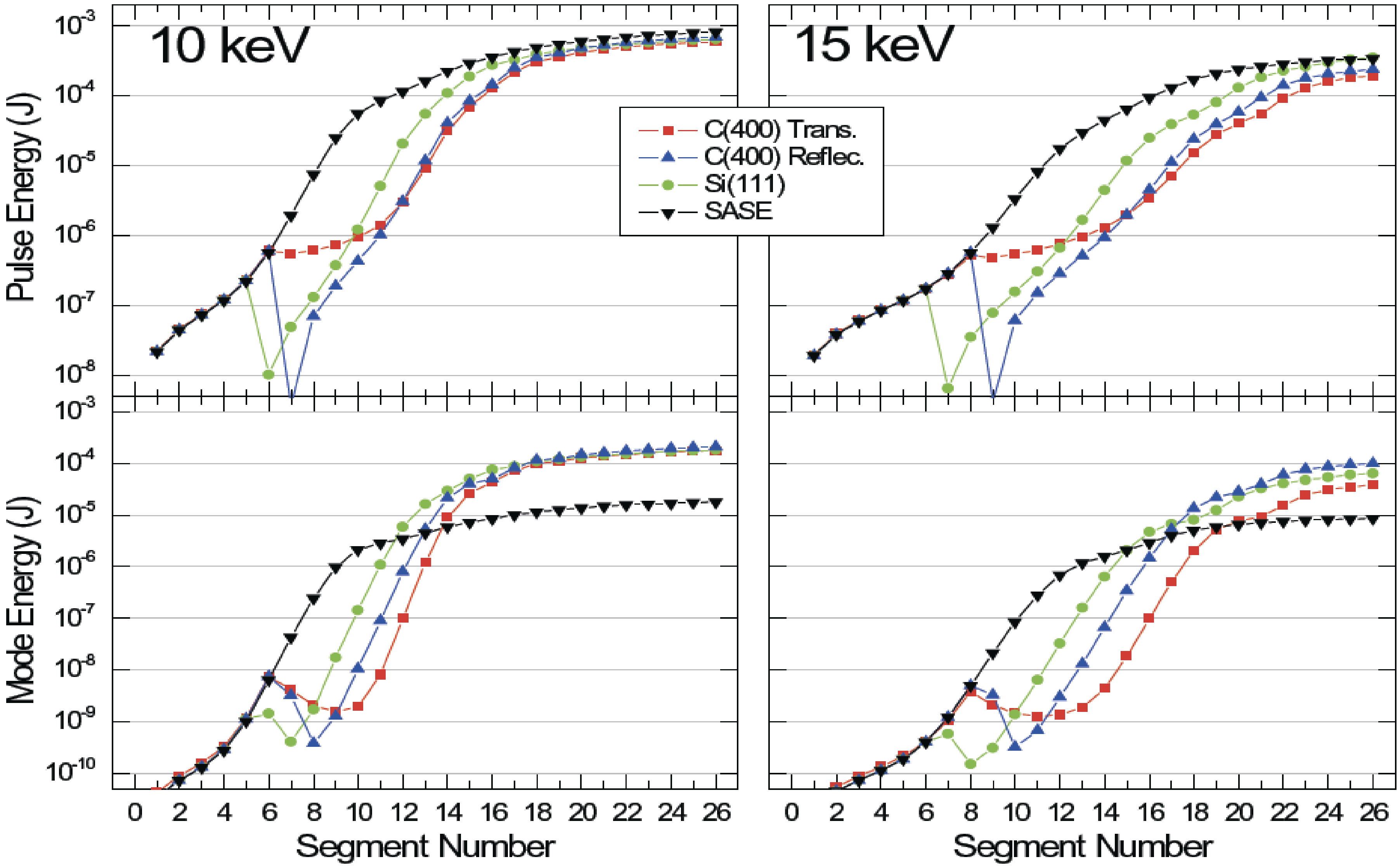
Enhancement ×10 after ID#18 ×5 after ID#24

Spectra



10 keV
15 keV
9980
9990
10000
10010
14970
14980
14990
15000
20 segs.
26 segs.
Photon Flux (10¹²photons/pulse/0.1% b.w.)
8
6
4
2
0
9993
9995
9997
14986
14988
14990
Photon Energy (eV)
Photon Energy (eV)

Comparison among different schemes



10 keV: Small difference

15 keV: Reflection geometry is more efficient

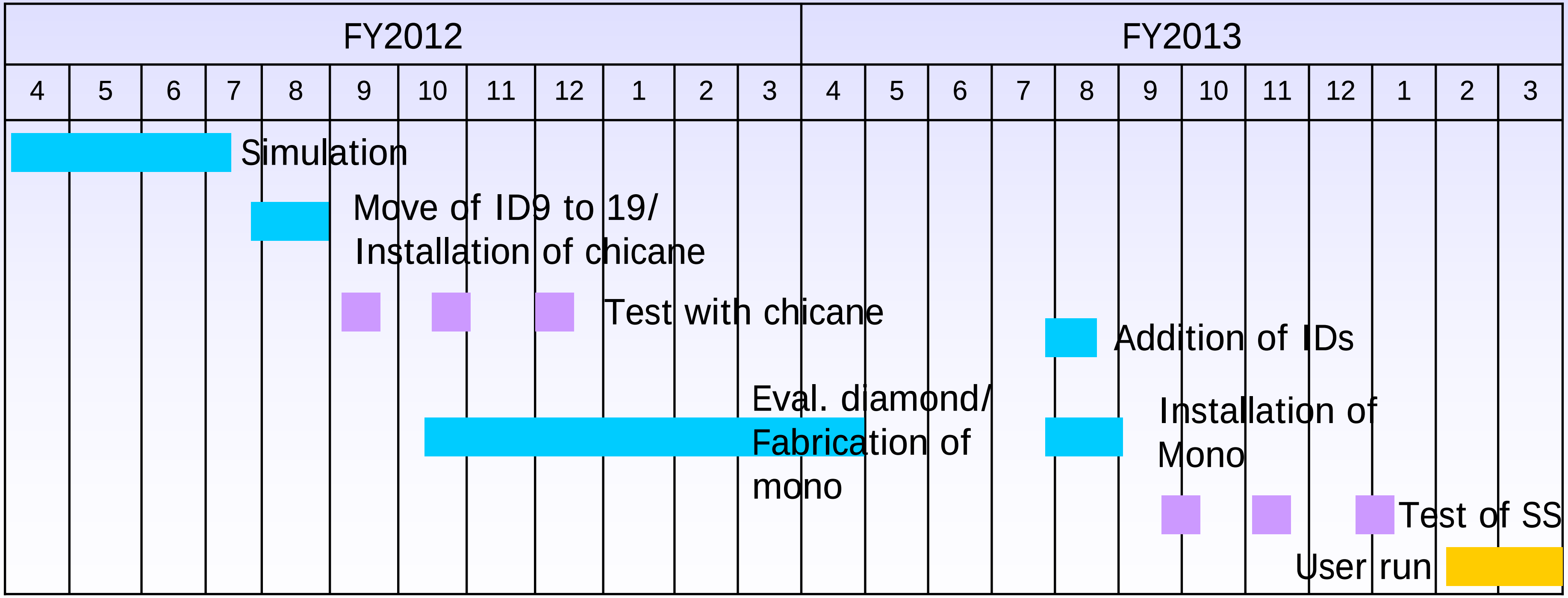
Plan

We start from diamond transmission geometry

Bragg angle 70~20 deg: 7.7 to 20 keV w C(400)

(~4) to 9.1 keV w C(111)

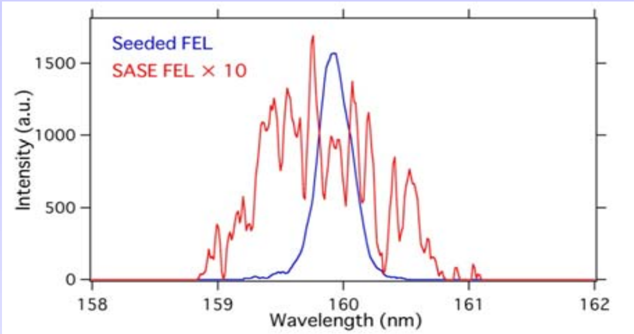
Remove ID#9 and install chicane and diamond mono



R&D for seeded SX-FEL: HHG studies at SCSS

160 nm (5th harmonics of TiS)

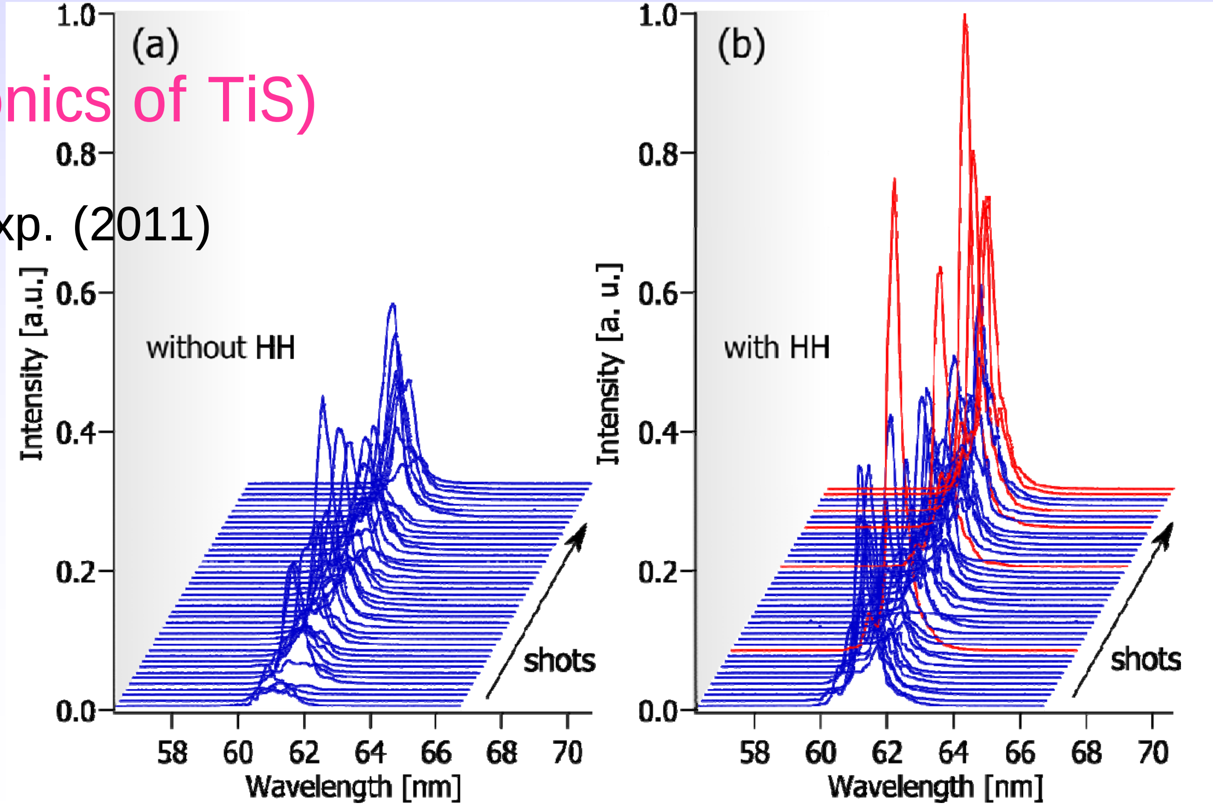
G. Lambert et al Nat. Phys. (2008)



61 nm (13th harmonics of TiS)

T. Togashi et al. Opt. Exp. (2011)

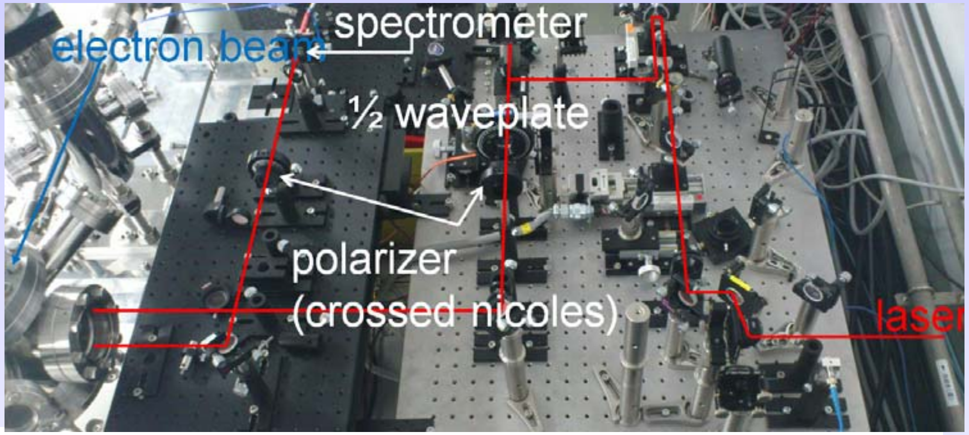
in collaboration with
Midorikawa Gr (RIKEN)
Yamanouchi Gr. (U. Tokyo)
Yamakawa Gr. (JAEA)

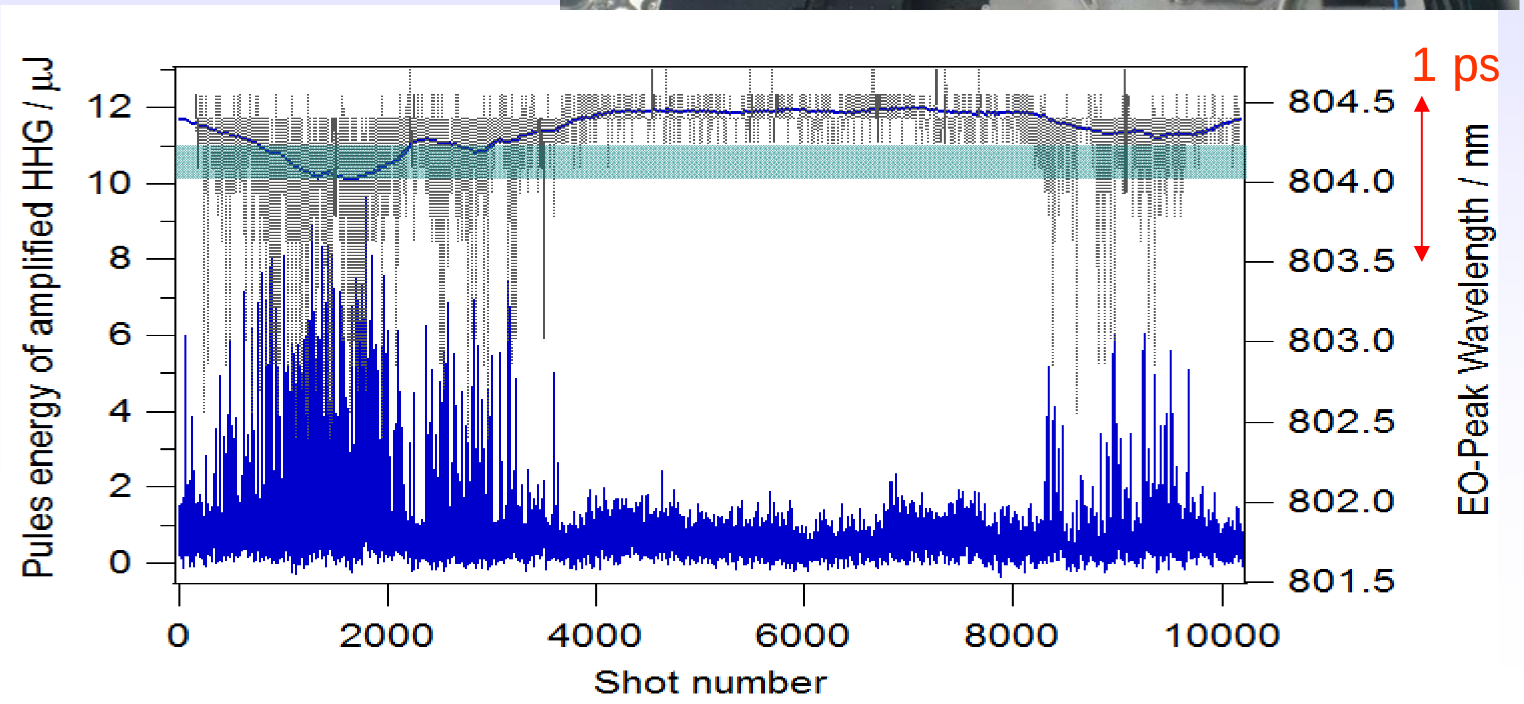


Temporal stabilization

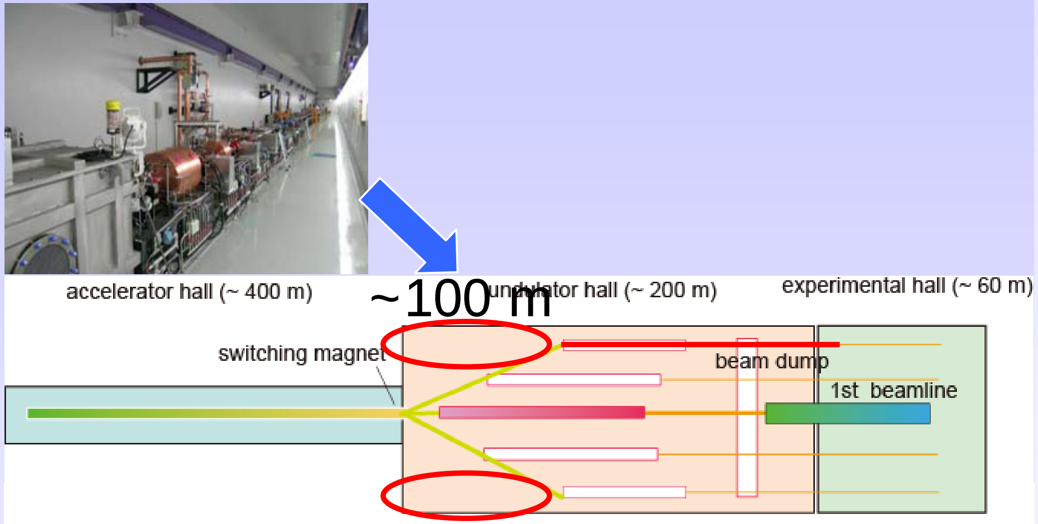
Spring of 2012:

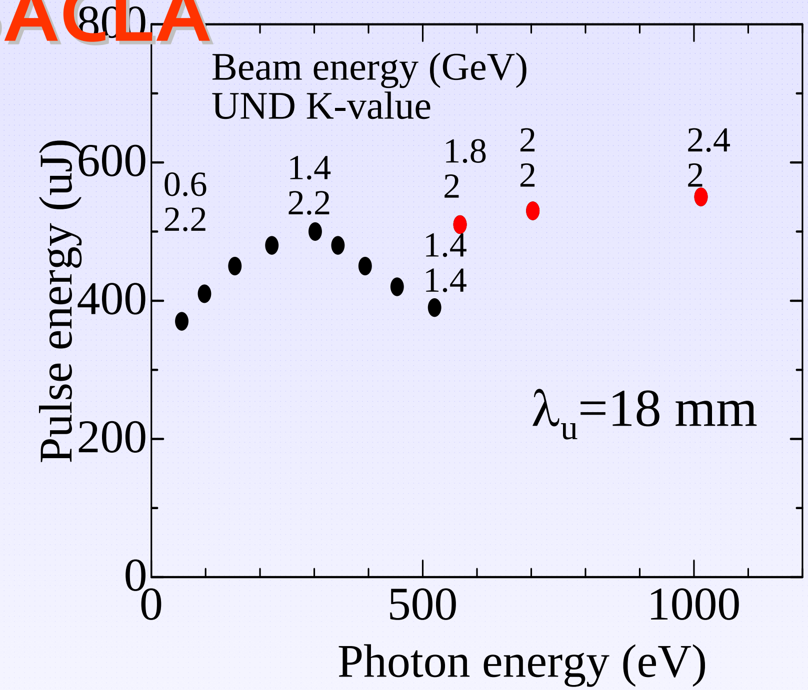
EOS (spectral decoding) tested for parallel monitoring of timing drift between e-beam and laser





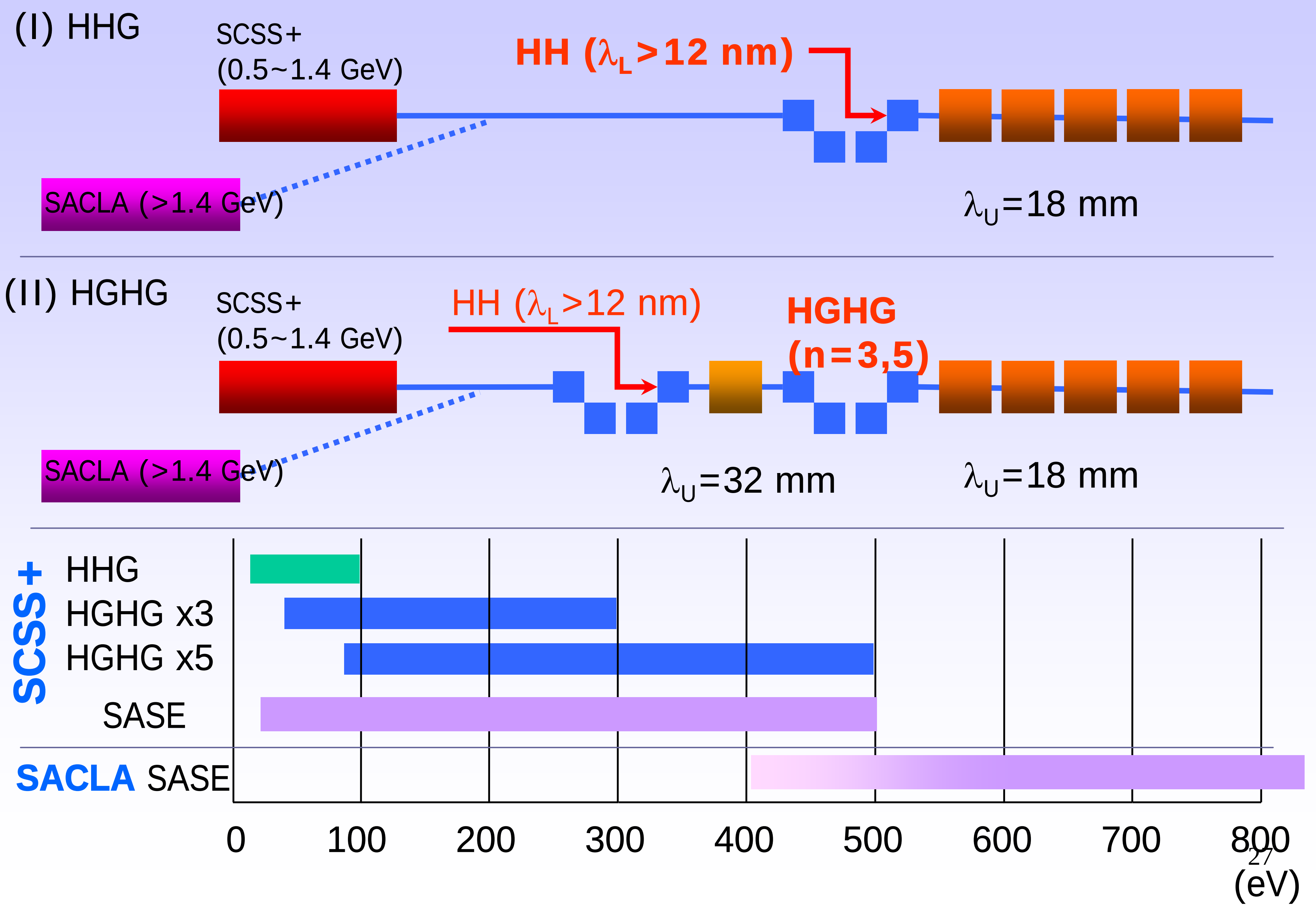
BL1 upgrade: SCSS+ into SACLA





- Space (~ 100 m) in undulator hall of SACLA enables us to install SCSS+ with increased beam energy from 250 MeV to ~1.4 GeV, which will cover $h\nu$~500 eV
- Significant advantages
  - Parallel operation of two beamlines without switching -> doubling of effective beamtime
  - Simultaneous utilization of XFEL and SXFEL (pump-probe etc.)
- SCSS+ will start in 2014, initially with 0.5 GeV

Plan



(I) HHG
SCSS+
(0.5~1.4 GeV)
HH (λL>12 nm)
SACLA (>1.4 GeV)
λU=18 mm
(II) HGHG
SCSS+
(0.5~1.4 GeV)
HH (λL>12 nm)
HGHG
(n=3,5)
SACLA (>1.4 GeV)
λU=32 mm
λU=18 mm
SCSS+
HHG
HGHG x3
HGHG x5
SASE
SACLA SASE
0
100
200
300
400
500
600
700
800
(eV)

Outlook

- Although we just started user operation in March, 2012, we see considerable demands from users for seeded XFEL operation, especially for material studies that require intense, monochromatic X-rays.
- We start modification of machine in this summer, and install monochromator in next summer.
- We hope to start seeded operation for users from early 2014.
- We are discussing to upgrade soft x-ray FEL line by installing SCSS+ into the accelerator tunnel and attaching some seeding options.

- We would like to continue collaboration with all of you and exchange of information for boosting science enabling with the ultimate, “fully-coherent” X-ray source.

Acknowledgement

All SACLA/SPring-8 Members

Especially,

Kensuke Tono, Tadashi Togashi, Takahiro Sato, Yuichi Inubushi, Tetsuo Katayama, Kanade Ogawa, Hiroaki Kimura, Hiromitsu Tomizawa, Y. Okayasu, S. Matsubara, T. Watanabe, M. Nagasono, Haruhiko Ohashi, Shunji Goto, Kazuaki Togawa, Inagaki, Yuji Otake, Maesaka, Toru Hara, Ryotaro Tanaka, Mitsuhiro Yamaga, Toru Ohata, Yukito Furukawa, Takashi Sugimoto, Hideo Kitamura, & Tetsuya Ishikawa

Yoshiro Fujiwara, Tekkon Kin, & Engineering Team

RIKEN Wako

Katsumi Midorikawa, Eiji Takahashi

Univ. of Tokyo

Kaoru Yamanouchi, Atsushi Iwasaki, S. Owada

JAEA

Koichi Yamakawa, Makoto Aoyama

Thank you for your attention

END